Threonine Needs of Broiler Chickens with Different Growth Rates[1,2]

M. T. Kidd,*,[3] A. Corzo,* D. Hoehler,† B. J. Kerr,‡ S. J. Barber,* and S. L. Branton§

*Department of Poultry Science, Mississippi State University, Mississippi State, MS 39759-9665; †Degussa Corporation, Kennesaw, Georgia 30144-3694; ‡Agriculture Research Service, United States Department of Agriculture, Ames, Iowa 50011-4420, and §Agriculture Research Service, United States Department of Agriculture, Mississippi State, Mississippi 39762-5367

ABSTRACT The Thr needs in 3 commercial broiler strains (A, multipurpose; B, high yield; C, high yield) known to differ in terms of feed intake, growth rate, and breast yield were evaluated. Birds were randomized across 96 floor pens (12 birds/pen), received a common diet from d 1 to 20, and were fed graduations of Thr (0.52 to 0.87% total Thr in 0.07% increments) from d 21 to 42. Treatments (3 × 6 factorial) were replicated 5 or 6 times. The corn, soybean meal, and peanut meal test diet contained 0.43 and 0.96% digestible Thr and Lys, respectively. An additional group of strain C birds (6 pens) was maintained on a corn-soybean meal diet containing surfeit Thr (0.73% of diet). Birds fed the corn and soybean meal diet performed similarly ($P \leq 0.05$) to birds fed peanut meal diets. A feed conversion interaction ($P \leq 0.05$) occurred indicating that strain C was more sensitive to Thr deficiency than strains A and B. The abdominal fat interaction ($P \leq 0.05$) indicated that strain A had more relative abdominal fat than strains B and C. All strains differed ($P \leq 0.05$) in terms of BW gain (A, 78.2; B, 75.1; C, 72.9 g/d). Strain C had the lowest ($P \leq 0.05$) feed intake, which resulted in the lowest ($P < 0.05$) Thr intake, but it had the highest ($P \leq 0.05$) breast meat yield. Most parameters tested yielded quadratic ($P \leq 0.05$) models whereby Thr estimates could be predicted. Namely, BW gain and breast meat yield resulted in total Thr estimates (95% of maximum response) of 0.74 and 0.71%, respectively, which are in close agreement with the 1994 NRC (0.74%). The plasma Thr sigmoid response verified the former estimates. Analysis of strain intercepts and slopes as affected by Thr differed ($P \leq 0.05$) in terms of feed intake but not BW gain or breast meat yield. The 21 to 42 d Thr need across strains was estimated as 0.74% total or 0.65% digestible. Because dietary Lys was not in excess of the bird's needs, the former digestibility estimate equated to a Thr/Lys of 0.68.

(*Key words*: amino acid, broiler strain, lysine, threonine)

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INTRODUCTION

Dietary amino acid concentration should closely meet maintenance and tissue accretion needs of commercial broilers, especially toward the middle and end of the growout period. Hence, under-and over-formulation of amino acids will decrease performance and increase nitrogen excretion, respectively. The former effects are exacerbated in the latter portion of rearing because the bird's feed consumption increases with age.

The nutrient Thr must be considered in dietary formulations for commercial broilers because its excess is costly and its deficiency will decrease the efficiency of TSAA and Lys use (Kidd, 2000). In addition, Thr is typically the third limiting amino acid behind TSAA and Lys in commercial broiler diets composed of corn or sorghum, soybean meal, and meat meal (Kidd, 2000).

Webel et al. (1996) fed graduations of Thr to Ross × Hubbard broilers from d 21 to 42 in a corn-peanut meal based diet and reported that optimal feed conversion occurred when dietary Thr was 0.61% digestible (0.70% total dietary Thr). In addition, Webel et al. (1996) concluded that the digestible Thr need should be expressed as 70% of the digestible Lys concentration. Penz et al. (1997) conducted a series of dose response experiments with wheat-corn gluten meal and sorghum-peanut meal based diets. They used Peterson × Arbor Acres male and female broilers (from 21 to 42 d) and concluded that the Thr requirement was no greater than 0.70% of diet. Kidd and Kerr (1997) fed graduations of Thr to Ross × Ross 308 male broilers in a corn-peanut meal based diet and determined that the live performance needs during from

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[3]To whom correspondence should be addressed: mkidd@poultry.msstate.edu.

30 to 42 d are satisfied with 0.70% total Thr. These live performance needs for Thr (Kidd and Kerr, 1997) are not in complete agreement with the former estimates (Penz et al., 1997; Webel et al., 1996), because they were obtained in the last half of the 21- to 42-d period. Moreover, Kidd and Kerr (1997) evaluated carcass traits and found that a higher level of Thr (0.78% total of diet) was needed to yield good breast meat accretion. Research reports had not previously documented the ability of Thr concentrations to heighten breast meat accretion when fed in excess of that needed to support growth. It was suggested, however, that because dietary Lys is critical for breast meat accretion, its optimization may require the presence of Thr levels higher than those needed to support growth (Kidd and Kerr, 1997).

As with most amino acids, variation exists in Thr requirement estimates. It has been indicated that bird age and dietary CP level are primarily responsible for the variation in published Thr values (Barkley and Wallis, 2001). Because variation exists in experiments controlling these former factors, feathering rate (Dozier et al., 2000a), immunity (Defa et al., 1999), or gut health (Bertolo et al., 1998) may also be affecting Thr needs. Research by Mack et al. (1999) evaluated graduations of Thr in male broilers (ISA and Ross) and determined that from 20 to 40 d, Thr needs varied from 0.52 to 0.61% digestible (0.59 to 0.68% total Thr). They reported that Thr needs for BW gain, feed conversion, and breast meat yield were consistently higher for Ross birds than those of ISA birds, which indicated that genetic differences in Thr needs exists when Thr is expressed as a percentage of diet (Mack et al., 1999). Although much recent research exists evaluating Thr needs of broiler chickens in the growing period, research delineating Thr needs for growing broilers across various genetic strains is sparse. Therefore, this study was conducted to measure Thr responses and quantify its need in 3 commercial genotypes known to differ in growth rate.

MATERIALS AND METHODS

Birds and Management

Three strains (A, B, and C) of broilers were evaluated in this study. Eggs from commercial broiler breeders were obtained when hens were 41, 43, and 46 wk of age for strains C, A, and B, respectively. Eggs were incubated in a common incubator and chicks hatched in a common hatcher. After hatch, chicks were feather sexed, and male birds were regrouped by strain. The vaccination program consisted of Marek's vaccination in ovo at d 18 of incubation and Newcastle and infectious bronchitis vaccinations at hatch. Chicks were then transported to a research facility and placed in pens (13 birds/pen) at d 1; the pens were 0.9 × 1.2 m and contained a tube feeder, a nipple water line, and built-up pine shavings. The curtain-sided facility was heated by forced-air furnaces and mixing fans used to distribute heat uniformly throughout the house. Incandescent lighting was used and provided 23L:1D during the experimental period. The temperature at d 1 was 37°C and was decreased to 30°C by 21 d of age. The high and low temperatures for the 21- to 42-d period were 27 and 24°C, respectively. Management and husbandry practices were in accordance with current standards (Guide for the Care and Use of Agriculture Animals in Agricultural Research and Teaching, 1991).

Design, Dietary Treatments, and Control Diet

Dietary treatments to evaluate Thr needs of broilers were used between 21 and 42 d of age. Broilers were fed common vegetable diets based on corn and soybean meal up to d 20 and contained 23% CP, 3,125 kcal of ME/kg, 1.27% Lys, 0.95% TSAA, 0.87% Thr, 0.90% Ca, 0.45% P (available), and 0.22% Na. At 21 d of age, 96 pens were equalized to 12 birds per pen, and dietary treatments were randomly distributed for the 21-d period. Dietary treatments consisted of 6 graduations of total Thr: 0.52, 0.59, 0.66, 0.73, 0.80, and 0.87% of diet. Treatments were achieved by the addition of crystalline L-Thr (98.5% Thr) at the expense of inert filler in the test diet containing 0.52% Thr (Table 1). The test diet primarily consisted of corn and peanut meal to create a diet whereby Thr would be the first limiting amino acid. To construct the dietary treatments, the diets containing 0.52 and 0.87% Thr were created in a horizontal ribbon mixer and steam pelleted. Appropriate aliquots of the 0.52 and 0.87% diets were remixed in a vertical mixer to create the remaining Thr graduation treatment levels. The 0.52 and 0.87% diets were also remixed so that pellet quality differences would not occur. Treatments containing 0.52, 0.59, 0.80, and 0.87% Thr were replicated 5 times per broiler strain. Treatments containing 0.66 and 0.73% Thr were replicated 6 times per broiler strain. Hence, there were 18 treatments arranged as a 3 (broiler strain) by 6 (dietary Thr) factorial design.

Although it has been shown that birds fed similar Thr levels in the growing period perform better when fed corn-peanut meal based diets vs. corn-soybean meal based diets (Kidd and Kerr, 1997), a separate group of birds from strain C were incorporated into the experiment (6 replications). These birds were fed a corn-soybean meal diet containing 0.73% total Thr (Table 1), and their growth rate was compared with strain C birds fed the test diet containing Thr graduations.

Intact protein-contributing ingredients were analyzed for CP (AOAC, 1995) and amino acids (Llames and Fontaine, 1994), and subsequent analyzed values were used in linear formulation of the test diet. The corn-peanut meal and corn-soybean meal based diets were analyzed for CP (AOAC, 1995). In addition, the corn and peanut meal based diets containing Thr graduations were analyzed for total amino acids (Llames and Fontaine, 1994).

Measurements

At d 42 before birds were handled to obtain BW, 2 birds per pen were removed, and venous puncture was

TABLE 1. Test diets for the 21 to 42 d period (% as is basis)

Ingredient	Corn-soybean-peanut	Corn-soybean[1]
Corn	61.075	65.363
Soybean meal	0.948	26.689
Peanut meal	26.222	—
Poultry fat	5.600	3.435
Dicalcium P	1.973	1.833
Limestone	1.046	1.079
NaCl	0.423	0.537
$NaHCO_3$	0.119	—
Vitamins and minerals[2]	0.250	0.250
DL-Met	0.311	0.246
L-Lys SO_4	1.035	0.254
L-Thr	—	0.042
L-Ile	0.188	0.035
L-Val	0.136	0.036
L-Arg	—	0.013
L-Trp	0.032	—
Filler[3]	0.400	0.050
Choline Cl	0.168	0.063
Coccidiostat[4]	0.075	0.075
ME, kcal/kg	3,150	3,150
CP, %	18.50	18.50
Thr, % of total	0.52	0.73
Thr, % digestible[5]	0.43	0.64
Lys, % total	1.08	1.08
Lys, % of digestible[5]	0.96	0.97
Thr-Lys, digestible[5]	0.45	0.66
TSAA, %	0.85	0.85
Ile, %	0.79	0.79
Arg, %	1.66	1.19
Val, %	0.89	0.89
Trp, %	0.20	0.24
Ca, %	0.90	0.90
P, % available	0.45	0.45
Na, %	0.23	0.23
DEB, mEq/kg[6]	150	186
Choline, mg/kg	1500	1500

[1]The corn soybean meal control diet had supplemental crystalline amino acids so that CP, in addition to Thr, is equal for the dietary validation experiment.

[2]Premix provided the following per kilogram of diet: vitamin A (vitamin A acetate) 7,718 IU; cholecalciferol 2,200 IU; vitamin E (source unspecified) 10 IU; menadione, 0.9 mg; B_{12}, 11μg; choline, 379 mg; riboflavin, 5.0 mg; niacin, 33 mg; D-biotin, 0.06 mg; pyridoxine, 0.9 mg; ethoxyquin, 28 mg; manganese, 55 mg; zinc, 50 mg; iron, 28 mg; copper, 7 mg; iodine, 1 mg; selenium, 0.2 mg.

[3]The dose titrations were achieved by addition of L-Thr at the expense of filler (sand).

[4]The Coccidiostat was Coban® 60 (Elanco Animal Health, Indianapolis, IN 46258) and provided 90 g of monensin sodium per ton of feed.

[5]Digestible amino acids were calculated from coefficients taken from Amino Dat™ 2.0 (Degussa Corporation, Kennesaw, GA 30144).

[6]Electrolyte balance represents dietary Na + K – Cl in mEq/kg of diet.

performed to collect blood. The plasma was frozen until analysis for Thr could be performed. Sulfosalicylic acid was used to deproteinate thawed plasma at 4°C. Free Thr in plasma was determined by precolumn derivatization and subsequent separation using an HPLC[4] analyzer.

Pen BW, feed intake, and mortality were measured for the 21- to 42-d period. The weight of mortality was used to correct feed intake data. At 42 d, 4 birds per pen were randomly weighed and processed. Birds were stunned with an electric knife, bled, scaled, and picked of feathers. Hocks, necks, viscera, and fat were removed manually. After carcasses were chilled in ice, breast muscles were removed manually.

[4]Beckman Coulter Instruments, Inc., Palo Alto, CA.

Statistical Analysis

The 18 treatments of the factorial arrangement of strain (3) and dietary Thr (6) were analyzed by the GLM procedure of SAS software (SAS Institute, 1998). Pen was the experimental unit for all analyses. Differences among means ($P \leq 0.05$) were separated with repeated *t*-test using the LSMEANS option of SAS software (SAS Institute, 1998). Linear, quadratic, and cubic models for Thr graduations were achieved by using the GLM procedure of SAS software (SAS Institute, 1998). When quadratic ($P \leq 0.05$), but not cubic ($P > 0.05$), responses occurred for a given parameter, recommended Thr concentrations were expressed by calculating 95% of the maximum or minimum response.

RESULTS

Analyses of Experimental Diets

The test diet based on corn, peanut meal, and soybean meal representing the intact protein contributing ingredients was formulated to contain 18.50% CP and was analyzed to contain 18.89% CP. Analyzed nitrogen in the corn and soybean meal based diet to validate the test diet containing peanut meal revealed a CP concentration of 18.46% as compared with the calculated concentration of 18.50%. Analyzed values of TSAA, Lys, and Thr in the peanut meal-based test diet were 0.80, 1.04, and 0.55%, respectively. Calculated and analyzed free L-Thr additions to this diet to establish the dose response were 0.00, 0.07, 0.14, 0.21, 0.28, and 0.35% of diet vs. 0.00, 0.07, 0.13, 0.18, 0.25, and 0.30% of diet, respectively.

Validation of Test Diets

Treatment differences ($P < 0.05$) occurred for strain C when comparing birds fed the corn and soybean meal diet to birds fed on the peanut meal-based test diet receiving varying Thr concentrations (data not presented). Birds fed the corn and soybean meal diet grew faster ($P \leq 0.05$; 73.3 g/bird per d) than those receiving 0.52 and 0.59% Thr in the test diet, but a similar growth rate was observed compared with birds receiving 0.66% Thr in the test diet. However, birds fed 0.73 to 0.87% Thr in the test diet grew better ($P \leq 0.05$) than birds receiving the corn and soybean meal diet.

Effects of Thr and Strain on Growth Performance Measurements

Growth performance measurements as affected by broiler strain and dietary Thr presented in Table 2 revealed an interaction ($P \leq 0.05$) for feed:gain. Broiler

TABLE 2. Live performance measurements of male broiler strains as affected by dietary graduations of Thr administered from 21 to 42 d of age

Treatment[1] Thr	Strain	Daily BW gain (g/bird)	Daily feed intake (g/bird)	Daily Thr intake (mg/bird)	Feed:gain[2,3]	Mortality (%)
0.52		55.0[d]	134.4[c]	699[f]	2.47[a]	6.67
0.59		69.5[c]	137.4[bc]	811[e]	1.96[b]	1.11
0.66		78.6[b]	142.0[b]	937[d]	1.81[c]	0.46
0.73		83.5[a]	148.1[a]	1,081[c]	1.77[c]	0.93
0.80		83.4[a]	148.3[a]	1,187[b]	1.75[c]	2.22
0.87		82.4[a]	151.4[a]	1,317[a]	1.79[c]	3.33
	A	78.2[a]	145.7[a]	1,021[a]	1.88	2.22
	B	75.1[b]	145.4[a]	1,018[a]	1.94	1.57
	C	72.9[c]	139.7[b]	976[b]	1.96	3.56
0.52	A	58.9	132.4	689	2.25[b]	8.33
0.52	B	56.3	133.9	696	2.39[b]	0.00
0.52	C	49.8	136.9	712	2.76[a]	11.67
0.59	A	73.9	139.0	820	1.87[cde]	1.67
0.59	B	68.7	140.5	829	2.02[c]	1.67
0.59	C	65.9	132.8	783	1.99[cd]	0.00
0.66	A	81.3	147.4	973	1.81[cde]	0.00
0.66	B	78.8	143.6	948	1.83[cde]	1.39
0.66	C	75.7	134.9	890	1.78[e]	0.00
0.73	A	84.5	151.3	1,104	1.79[de]	0.00
0.73	B	82.9	149.0	1,088	1.80[de]	1.39
0.73	C	83.1	144.0	1,051	1.72[e]	1.39
0.80	A	85.5	153.4	1,227	1.77[e]	1.67
0.80	B	83.3	150.9	1,207	1.77[e]	3.33
0.80	C	81.4	140.7	1,126	1.72[e]	1.67
0.87	A	85.3	150.8	1,312	1.76[e]	1.67
0.87	B	80.3	154.2	1,341	1.85[cde]	1.67
0.87	C	81.5	149.1	1,297	1.76[e]	6.67
SEM		1.63	3.77	23.8	0.073	3.13
Source of variation						
Thr		0.001	0.001	0.001	0.001	0.288
Strain		0.001	0.011	0.002	0.142	0.593
Thr × strain		0.359	0.592	0.444	0.009	0.505
Thr linear		0.001	0.175	0.010	0.001	0.019
Thr quadratic		0.001	0.381	0.977	0.001	0.017
Thr Requirement prediction						
T recommendation[4]		0.74	NA[6]	NA	NA	0.67
D recommendation[5]		0.65	NA	NA	NA	0.58
Regression equation r^2		0.85	NA	NA	NA	0.07

[a-e]Means within a continuous column with no common superscripts differ ($P \le 0.05$).

[1]Dietary treatments represent total levels of Thr (% of diet). Strains represent male broilers from multipurpose (strain A) and high-yield (strains B and C) commercial crosses.

[2]Feed:gain represents grams of feed consumed divided by grams of BW gain accreted. The weight of mortality (g) was added to the weight of BW gain.

[3]A cubic ($P = 0.006$) response for feed:gain was noted.

[4]T recommendation indicates the total Thr (% of diet) recommended level for a given parameter as estimated by 95% of the maximum or minimum response from the quadratic equation ($P \le 0.05$).

[5]D recommendation indicates the digestible Thr (% of diet) recommended level for a given parameter as estimated by 95% of maximum or minimum response from the quadratic equation ($P \le 0.05$).

[6]NA = not applicable due to lack of significance ($P \le 0.05$) in the quadratic model.

strains fed surfeit Thr (0.73%), in addition to 0.59 and 0.66% Thr, had equal ($P \le 0.05$) feed:gain responses. However, strain C had a poorer ($P \le 0.05$) feed:gain response vs. strains A and B when fed diets containing 0.52% Thr.

Birds fed Thr graduations had improved ($P \le 0.05$) daily BW gain as Thr increased to 0.73% of diet (Table 2). Also, daily feed intake was similar as birds fed 0.73% Thr had heightened ($P \le 0.05$) feed intake relative to birds fed lower levels of Thr. However, birds fed each progressive Thr level had increased ($P \le 0.05$) daily Thr intake, up to 0.87% Thr of diet. The lowest ($P \le 0.05$) feed:gain was observed in birds fed 0.66% Thr vs. birds fed 0.52 and 0.59% Thr. No dietary Thr main effect ($P \le 0.05$) in mortality occurred.

Strains differed ($P \le 0.05$) in terms of daily BW gain with strain A having the highest gain, and strain C having the lowest gain (Table 2). Strain C had lower daily feed and daily Thr intake ($P \le 0.05$) than strains A and B. Differences ($P \le 0.05$) in feed:gain and mortality for strain main effects did not occur.

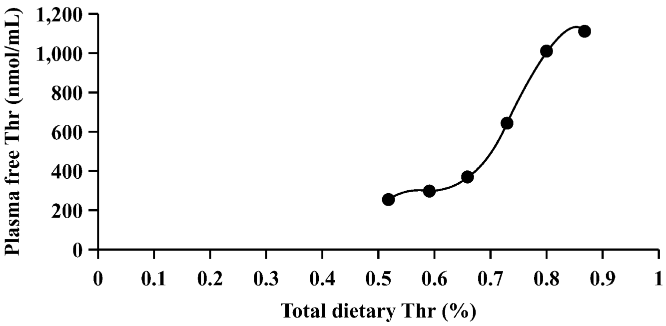

FIGURE 1. The response of dietary Thr on plasma free Thr was sigmoidal. Probability values for the main effect of Thr, the main effect of strain, and the Thr x strain interaction were 0.001, 0.834, and 0.261, respectively. Linear, quadratic, and cubic ($P \leq 0.05$) responses were obtained for plasma free Thr.

Linear and Nonlinear Models for Growth Performance Measurements as Affected by Dietary Thr

Quadratic models whereby recommendations could be predicted ($P \leq 0.05$) for growth performance measurements (Table 2) include daily BW gain (g/bird per d) and mortality (%). Prediction equations for BW gain and mortality are $Y = -172.46 + 655.65 \times Thr - 417.85 \times Thr^2$ and $Y = 75.82 - 212.03 \times Thr + 148.81 \times Thr^2$, respectively, where Y represents the parameter of interest and Thr represents the percentage of total dietary Thr. Daily feed intake data did not fit a quadratic ($P \leq 0.05$) regression model. However, daily Thr intake increased ($P \leq 0.05$) linearly as dietary Thr increased. A cubic model ($P \leq 0.05$) and a quadratic model ($P \leq 0.05$) for feed:gain was observed. Therefore, Thr recommendations for feed:gain were not predicted.

Plasma Thr

The sigmoidal response of plasma free Thr as affected by dietary Thr is presented in Figure 1. Birds fed Thr graduations had increased ($P \leq 0.05$) plasma free Thr as Thr increased to 0.80% of diet (Table 2). Strain or Thr × strain interactions ($P \leq 0.05$) did not occur for plasma free Thr. Dietary Thr affected ($P \leq 0.05$) plasma free Thr in a cubic manner.

Effects of Thr and Strain on Carcass Measurements

A dietary Thr × strain interaction occurred for percentage abdominal fat (Table 3). Across strains, birds fed 0.52, 0.59, 0.73, and 0.87% dietary Thr had equal ($P \leq 0.05$) percentages of abdominal fat. However, strain A had a higher ($P \leq 0.05$) percentage of abdominal fat than strains B and C when the birds were fed 0.66% Thr. Strain A had a higher ($P \leq 0.05$) percentage of abdominal fat vs. strain C, and strain B was intermediate when Thr was fed at 0.80% of diet.

All carcass measurements, except abdominal fat weight, were affected by the main effect of dietary Thr (Table 3). Processing BW and percentage of fat followed similar patterns in that the optimum weight and percentage, respectively, occurred at 0.87% Thr and differed ($P \leq 0.05$) from 0.52, 0.59, and 0.66% Thr. Birds fed 0.73% dietary Thr had better ($P \leq 0.05$) carcass and breast meat weight vs. those receiving 0.52 through 0.66% dietary Thr. However, carcass and breast meat yield were increased ($P \leq 0.05$) as dietary Thr was increased from 0.52 to 0.59% of diet. Increasing dietary Thr from 0.59 to 0.73% further improved ($P \leq 0.05$) carcass and breast meat yield, but intermediate yields were observed in birds fed on 0.66% dietary Thr.

Processing BW, carcass weight, and breast meat yield (but not carcass yield, breast meat weight, or percentage fat) were affected ($P \leq 0.05$) by strain (Table 3). Strain C had lower ($P \leq 0.05$) processing BW, carcass weight, and fat weight vs. strains A and B. However, strain C had increased ($P \leq 0.05$) breast meat yield in comparison with strain A; strain B had an intermediate breast meat yield.

Linear and Nonlinear Models for Carcass Measurements as Affected by Dietary Thr

Prediction equations generated from the quadratic models ($P \leq 0.05$; Table 3) for processing BW (kg), carcass weight (kg), breast meat weight (kg), carcass yield (%), and breast meat yield (%) were $Y = -1.69 + 10.34 \times Thr - 6.44 \times Thr^2$, $Y = -1.70 + 8.63 \times Thr - 5.40 \times Thr^2$, $Y = -0.84 + 3.35 \times Thr - 2.14 \times Thr^2$, $Y = 46.26 + 64.24 \times Thr - 41.48 \times Thr^2$, and $Y = -7.19 + 70.11 \times Thr - 46.47 \times Thr^2$, respectively. Recommended Thr needs for carcass measurements as predicted by calculating 95% of the maximum or minimum response of the quadratic model ($P \leq 0.05$) varied from 0.71 to 0.76% total or 0.62 to 0.67% digestible Thr of diet. Quadratic models were not fitted ($P \leq 0.05$) for the weight or percentage of abdominal fat.

Intercepts and Slopes of Strains as Affected by Dietary Thr

Recommended Thr needs did not differ ($P \leq 0.05$) among strains for BW gain and breast meat yield (Table 4). However, the intercepts and slopes of strains A and B differed ($P \leq 0.05$) from strain C in terms of feed intake. The feed intake recommendation for strain A was calculated to be 0.76% Thr.

DISCUSSION

Broiler diets containing corn, soybean meal, and poultry meal typically result in Thr being the third limiting amino acid. Commercial broilers change rapidly due to the efficiency of genetic selection. As a result, commercial broilers differ greatly in terms of growth rate and carcass and breast yield potentials. This study evaluated Thr needs in 3 commercial broiler strains that differed in terms of growth rate and yield potential. In doing so, the aim

TABLE 3. Processing attributes of male broiler strains as affected by dietary graduations of Thr administered from 21 to 42 d of age

Treatment[1]		Processing	Carcass[2]		Breast[2,3]		Leaf fat[2]	
Thr	Strain	BW (kg)	Weight (kg)	Yield (%)	Weight (kg)	Yield (%)	Weight (kg)	Percentage (%)
0.52		1.938[d]	1.320[d]	68.26[c]	0.322[d]	16.62[c]	0.031	1.62[a]
0.59		2.170[c]	1.519[c]	69.99[b]	0.393[c]	18.13[b]	0.030	1.40[b]
0.66		2.350[b]	1.660[b]	70.66[ab]	0.441[b]	18.77[ab]	0.034	1.43[b]
0.73		2.424[ab]	1.722[a]	71.07[a]	0.470[a]	19.41[a]	0.033	1.35[bc]
0.80		2.430[ab]	1.717[ab]	70.66[ab]	0.457[ab]	18.81[ab]	0.034	1.39[bc]
0.87		2.450[a]	1.739[a]	71.00[a]	0.460[ab]	18.78[ab]	0.031	1.25[c]
	A	2.343[a]	1.648[a]	70.26	0.422	17.97[b]	0.034[a]	1.44
	B	2.314[a]	1.619[a]	69.94	0.427	18.40[ab]	0.033[a]	1.42
	C	2.224[b]	1.572[b]	70.62	0.422	18.90[a]	0.030[b]	1.35
0.52	A	1.965	1.353	68.85	0.323	16.41	0.027	1.37[cdef]
0.52	B	2.275	1.590	69.87	0.406	17.85	0.032	1.41[bcde]
0.52	C	2.396	1.683	70.24	0.426	17.80	0.038	1.58[bc]
0.59	A	2.433	1.741	71.57	0.472	19.43	0.036	1.49[bcd]
0.59	B	2.495	1.752	70.21	0.446	17.88	0.034	1.38[cdef]
0.59	C	2.495	1.766	70.83	0.461	18.48	0.035	1.42[bcde]
0.66	A	2.035	1.354	66.80	0.333	16.34	0.037	1.84[a]
0.66	B	2.14	1.507	70.41	0.388	18.10	0.030	1.40[bcdef]
0.66	C	2.367	1.675	70.74	0.457	19.29	0.033	1.38[cdef]
0.73	A	2.471	1.748	70.72	0.470	19.02	0.033	1.33[def]
0.73	B	2.430	1.718	70.69	0.451	18.55	0.034	1.40[bcdef]
0.73	C	2.440	1.715	70.27	0.466	19.08	0.029	1.18[ef]
0.80	A	1.815	1.254	69.11	0.310	17.13	0.030	1.64[ab]
0.80	B	2.095	1.460	69.69	0.387	18.46	0.029	1.40[bcdef]
0.80	C	2.288	1.624	70.99	0.441	19.22	0.031	1.33[def]
0.87	A	2.367	1.678	70.93	0.468	19.79	0.029	1.23[ef]
0.87	B	2.365	1.681	71.08	0.474	20.02	0.032	1.37[cdef]
0.87	C	2.415	1.736	71.90	0.454	18.79	0.028	1.15[f]
SEM		0.0534	0.0401	0.578	0.0159	0.476	0.0023	0.090
Source of variation								
Thr		0.001	0.001	0.001	0.001	0.001	0.270	0.001
Strain		0.001	0.005	0.134	0.804	0.005	0.009	0.214
Thr × strain		0.805	0.929	0.232	0.839	0.434	0.053	0.016
Thr linear		0.001	0.001	0.001	0.001	0.001	0.116	0.264
Thr quadratic		0.001	0.001	0.001	0.001	0.001	0.121	0.415
Requirement predictions								
T recommendation[4]		0.76	0.76	0.73	0.74	0.71	NA[6]	NA
D recommendation[5]		0.67	0.67	0.64	0.65	0.62	NA	NA
Regression equation r^2		0.64	0.72	0.32	0.69	0.37	NA	NA

[a-f]Means within a continuous column with no common superscripts differ ($P \leq 0.05$).

[1]Dietary treatments represent total levels of Thr (% of diet). Strains represent male broilers from multipurpose (strain A) and high-yield (strains B and C) commercial crosses.

[2]Yield and percentage data are relative to processing BW.

[3]Represents pectoralis major and Pectoralis minor.

[4]T recommendation indicates the total Thr (% of diet) recommended level for a given parameter as estimated by 95% of the maximum response from the quadratic ($P \leq 0.05$) equation.

[5]D recommendation indicates the digestible Thr (% of diet) recommended level for a given parameter as estimated by 95% of the maximum response from the quadratic ($P \leq 0.05$) equation.

[6]NA = not applicable due to lack of significance ($P \leq 0.05$) in the quadratic model.

was to maximize growth of the birds in the starting and growing periods so that the Thr estimates would be accurate. Interpretation of amino acid experiments involving dose response methodology can be restricted if broiler growth is compromised as a result of a diet that limits feed intake or is limiting in an essential nutrient. In the study presented herein and in others evaluating Thr needs of growing (Kidd and Kerr, 1997) and finishing (Kidd et al., 1999) male broilers, corn-peanut meal diets containing surfeit Thr allowed for better growth than broilers being fed on corn-soybean meal diets containing equal Thr and other essential amino acids. Therefore, the Thr recommendations presented from the dose responses among strains should be good estimates for minimums in feed formulation for commercial broilers. Further, Thr analyses of test diets were in agreement with calculated concentrations validating the presence of a dose response.

Mack et al. (1999) evaluated Thr needs for 2 broiler strains for the 20- to 40-d period. Although dose response experiments that Mack et al. (1999) used to predict Thr needs were conducted at different institutions, the experimental diets formulated for the dose responses by Mack et al. (1999) were identical. The estimated Thr requirement in Ross male broilers was 8% higher than that of ISA male broilers (Mack et al., 1999). Additional research reports evaluating Thr needs in broiler strains of identical ages

TABLE 4. Analysis of BW gain, feed intake, and breast meat yield intercepts and slopes of male broiler strains (21 to 42 d of age) as affected by dietary Thr (0.52 to 0.87% total of diet)

Strain	Intercept	Linear slope	Quadratic slope	95% Maximum[1]
BW gain (g/bird per d)				
A	–142.096	579.996	–367.542	0.75
B	–171.533	658.596	–424.507	0.73
C	–203.763	728.347	–461.488	0.75
Feed intake (g/bird per d)				
A	–15.195[b]	417.082[a]	–259.280[b]	0.76
B	69.690[b]	164.366[a]	–77.543[b]	NA[2]
C	178.637[a]	–156.436[b]	140.534[a]	NA
Breast meat yield (% of processing BW)				
A	–3.357	57.943	–38.064	0.72
B	–8.004	71.977	–47.482	0.72
C	–10.209	80.410	–53.854	0.71

[a,b]Denotes differences ($P < 0.05$) in slopes and intercepts within a continuous column.

[1]Represents total percentage of dietary Thr at 95% of the maximum response of the quadratic ($P \leq 0.05$) model.

[2]NA = not applicable.

are sparse, but similar research conducted with other amino acids (i.e., Lys) is not. Han and Baker (1991) fed Hubbard × Hubbard and New Hampshire × Columbian male broiler chicks graduations of dietary Lys (0.62 to 1.52% total of diet) from 8 to 21 d of age. The Hubbard broilers responded to over twice as much daily Lys as the lightweight cross to support BW gain (Han and Baker, 1991). It was indicated that protein gains as a function of total BW gain were 16.8 and 16.9% in Hubbard and New Hampshire × Columbian chicks, respectively (Han and Baker, 1991). Moreover, the increased feed intake of the Hubbard broilers provided the needed Lys to satisfy its genetic potential to grow. In practice, however, it is difficult to supply dietary amino acids on an intake basis because feed intake increases rapidly throughout life in a broiler, and broilers remain on diets over periods of 2 wk. Although broiler strains in the study presented herein had different feed intakes, recommended Thr needs for BW gain (0.73 and 0.75%) and breast meat yield (0.71 and 0.72%) were similar on a percentage of diet basis.

Few interactions occurred between broiler strain and dietary Thr. The interaction in percentage abdominal fat indicates that fat deposition among strains is the same when fed deficient (0.52 and 0.59% Thr), surfeit (0.73% Thr), and high (0.87% Thr) dietary Thr. However, the high percentage fat content of strain A in comparisons to strains B and C when fed a marginal Thr level (0.66% Thr) may be partly explained by the high consumption of feed by strain A to compensate for the Thr limitation. Indeed, strains B and C were less sensitive to deficient or marginal dietary Thr in terms of feed intake as noted by a lack of a quadratic fit for feed intake.

Diets formulated to contain doses of crystalline amino acids can impact the amino acid pattern of portal blood in a sigmoidal manner (Morrison et al., 1961). Plasma obtained from birds in this study responded to dietary Thr in a sigmoidal manner. Hence, plasma Thr increased slowly as Thr increased below recommended levels (0.52, 0.59, and 0.66% of diet), increased sharply as Thr increased to and above recommended levels (0.73 and 0.80% Thr), and reached a plateau as Thr increased to 0.87%. The sigmoidal pattern of the plasma is also in agreement with research evaluating Thr needs of female broilers from 30 to 42 d of age (Corzo et al., 2003).

Research reports evaluating Thr needs of male broilers in the growing time period have predicted total Thr needs for live performance ranging from 0.59% of diet (Mack et al., 1999) to 0.70% of diet (Webel et al., 1996; Kidd and Kerr, 1997; Penz et al., 1997). Kidd and Kerr (1997) found that breast meat accretion responded up to 0.78% total Thr of diet during the 30- to 42-d period. However, some subsequent research on male broilers in the finishing period (42 to 56 d) has demonstrated that the Thr need for breast meat is higher than that of growth (Dozier et al., 2000b), whereas others have not (Kidd et al., 1999; Kidd et al., 2003). In the current study the recommendation for Thr in terms of BW gain for male broilers was 0.74% of diet (0.65% digestible Thr), but the Thr recommendation for breast meat yield was 0.71% (0.62% digestible Thr). Breast meat weight, however, responded up to 0.74% total dietary Thr (0.65% digestible Thr). In conclusion, the NRC (1994) Thr estimate appears to be very accurate for 3 male commercial broiler strains. Although the aim of this study was to predict Thr responses across strains, the Lys level of the test diet allows for extrapolation of an ideal ratio. Hence, Lys was not in excess of the bird's need (Kidd et al., 1998). Using a digestible Thr need of 0.65% of diet results in an optimum Thr:Lys of 68%.

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